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An experimental study on performance during reverse cycle defrosting of an air source heat pump with a horizontal three-circuit outdoor coil

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Abstract

When the surface temperature of the outdoor coil in an air source heat pump (ASHP) unit is below both the air dew point and freezing point of water, frost can be formed and accumulated over the surface of the outdoor coil, which is usually of multi-circuit structure in order to minimize its refrigerant pressure loss and enhance the heat transfer between refrigerant and ambient air. However, frosting adversely affects the operational performance and hence the energy efficiency of the ASHP unit, therefore periodic defrosting is necessary. Currently, the most widely standard defrosting method used for ASHP units is reverse cycle defrosting. A previous related study has suggested that during reverse cycle defrosting, downwards flowing of melted frost due to gravity over a vertical multi-circuit outdoor coil in an ASHP unit could deteriorate defrosting performance, by using more energy for defrosting and prolonging a defrosting process. If however an outdoor coil can be horizontally installed, the flow path for melted frost over coil surface can be shortened, and a better defrosting performance expected. In this paper, therefore, an experimental study on performance during reverse cycle defrosting of an ASHP unit having a horizontal three-circuit outdoor coil has been carried out. Firstly, a detailed description of the ASHP unit is presented. This is followed by reporting the experimental results. Finally, a comparative and quantitative analysis is given.

Keywords: Air source heat pump; Defrosting; Melted frost; Experiment; Multi-circuit; Horizontal

1 Introduction

When an air source heat pump (ASHP) unit is used for space heating in cold and high humidity environments, frost can be formed and accumulated over the surface of its outdoor coil. Frosting deteriorates its operational performance and energy efficiency, and reduces its output heating capacity, therefore periodic defrosting is necessary. Currently, reverse cycle defrosting is the most widely used

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standard defrosting method. When an ASHP unit is operated at a reverse cycle defrosting mode, its outdoor coil is usually installed vertically for floor space saving. Among the reported experimental studies on defrosting, most attentions were paid to the performance improvement for an ASHP unit, such as system dynamics during defrosting [1], component optimization [2], and defrosting control [3]. On the other hand, the downwards flowing of the melted frost helps form or reinforces a water layer between the frost and the coil surface, which introduces a thermal resistance and thus reduces the heat transfer between the two. It was reported that for a vertical outdoor coil, when defrosting at its top circuits was ended, the bottom ones were still covered with frost [4]. Therefore, allowing the melted frost to flow downwards on the surface of a vertical outdoor coil in an ASHP unit due to gravity would have a negative effect on defrosting performances.

To mitigate the negative effects, a previous study suggested that a vertically installed multi-circuit outdoor could be installed horizontally [5]. In this way, the flow path for melted frost over coil surface can be shortened, and a better defrosting performance expected. However, only a limited number of related studies may be identified in open literature. Notably, Abdel-Wahed et al. experimentally studied defrosting over a horizontal flat plated cooling surface. The results indicated that a decrease in the thickness of frost layer was approximately linear with defrosting time [6]. However, hot water defrosting was used. Later, Hambraeus et al. [7] studied an experimental horizontal evaporator. However, the attentions were not on melting frost. Therefore, an experimental study on reverse cycle defrosting performance for an ASHP unit having a horizontal multi-circuit outdoor coil has been carried out and the study results are reported in this paper.

2. Experimentation

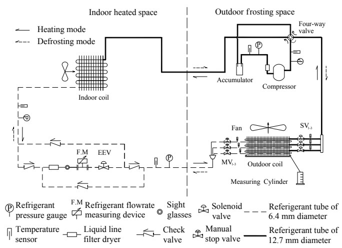

Fig. 1 Schematics of the experimental ASHP unit installed in an environmental chamber

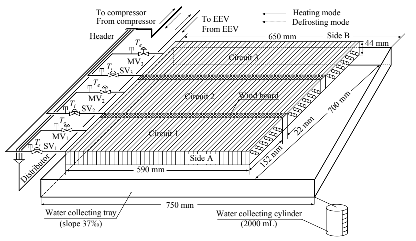

Fig. 2 Details of a three-parallel refrigerant circuit outdoor coil and the locations of solenoid valves (SV) and manual stop valves (MV)

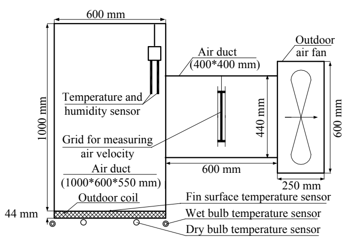

Fig. 3 The airside details of the outdoor coil in the experimental ASHP unit installed in the frosting outdoor space

Table 1 Experimental conditions

Item	Parameters	Values
1	Air temperature in indoor heated space (ºC)	20
2	Air temperature in outdoor frosting space (ºC)	0.5±0.2
3	Air relative humidity in outdoor frosting space (%)	90±3
4	Face velocity of outdoor coil (m/s)	1.2[a]
5	Face velocity of indoor coil at defrosting mode (m/s)	2.31
6	Face velocity of indoor coil at heating (frosting) mode (m/s)	3.68
7	Heating (frosting) operation duration (min)	60

An An experimental ASHP unit was specifically established for carrying out the experimental work. Fig. 1 shows the schematics of the ASHP unit installed in an environmental chamber where there was an indoor heated space and a frosting outdoor space. The outdoor coil was specially designed and made for this study, as shown in Fig. 2. Fig. 3 shows the airside details of the outdoor coil in the experimental ASHP unit installed in the frosting outdoor space.

Series of experimental work using the experimental ASHP unit have been carried out to study the effects of frost melting and water retention on the surface of a horizontal three-circuit outdoor coil in an ASHP unit on performance during reverse cycle defrosting. Tables 1 and 2 show the details of the experimental conditions and three studied cases, respectively.

Table 2 Three experimental cases

Case No.	Experimental conditions
1	Turn off the outdoor air fan
2	Turn off the outdoor air fan and clean the melted frost manually for 30 s when the tube temperature was 2 ºC
3	Turn on and reverse the rotation of the outdoor air fan for 40 s when the tube temperature was 3 ºC

3. Experimental results

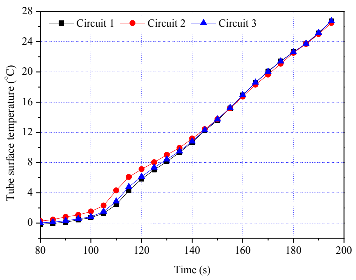

Fig. 4 Measured tube surface temperatures (Case 1)

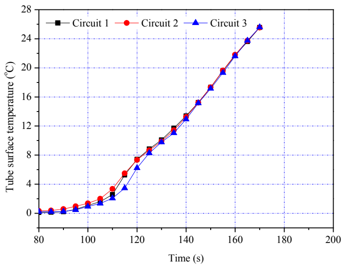

Fig. 5 Measured tube surface temperatures (Case 2)

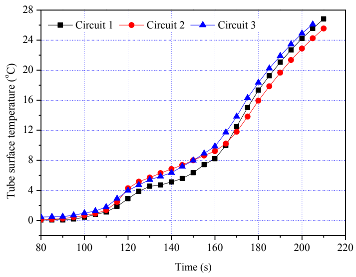

Fig. 6 Measured tube surface temperatures (Case 3)

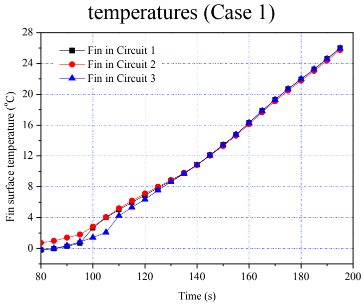

Fig. 7 Measured fin temperatures (Case 1)

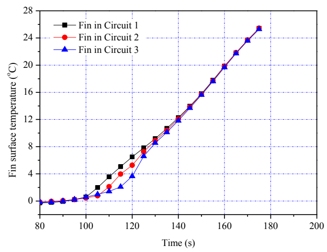

Fig. 8 Measured fin temperatures (Case 2)

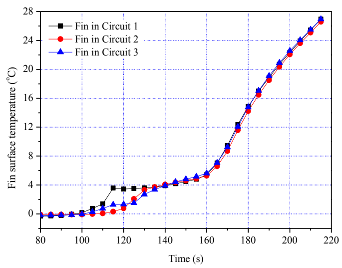

Fig. 9 Measured fin temperatures (Case 3)

The measured operating performances of the experimental ASHP unit during defrosting, corresponding to the three experimental cases, are presented in Figs. 4-9. In all these figures, for their time (horizontal) axis, 80 s is the chosen starting time for defrosting in order to clearly show the temperature rise during defrosting. Figs. 4-6 show the measured tube surface temperatures at the exit of each of the three circuits, and Figs. 7-9 the measured fin temperatures at the center of each circuit. Table 3 shows the experimental results for the three cases.

As seen from Figs 4 and 7, the termination points for each circuit in Case 1 occurred the same time, at 185 s, where the measured surface temperature were all at 24 ºC. Therefore, the negative effects of downwards flowing of the melted frost due to gravity could be alleviated by using a horizontally installed multi-circuit outdoor coil. For Case 2, most of the melted frost was drained away, with a significantly reduced defrosting duration of 165 s. However, the negative effects of melted frost retained on the airside surface of the experimental three-circuit outdoor coil due to surface tension on performance during reverse cycle defrosting were also demonstrated. Moreover, a further measure of reversing the rotation of the outdoor air fan to blow away the melted frost was studied. Although much of melted frost was blown away, the heat loss to ambient cold air from the surfaces of tubes and fins due to enhanced convective heat transfer actually prolonged a defrosting duration to 205 s.

Table 3 Experimental results

Case No.	Defrosting duration	Residual water collected	Total melted frost collected	Results shown in
1	185 s	566 g	948 g	Figs 4 and 7
2	165 s	42 g	909 g	Figs 5 and 8
3	205 s	393 g	937 g	Figs 6 and 9

4. Conclusions

A special experimental setup was built, and the negative effects of the downwards flowing of the melted frost due to gravity could be alleviated by using a horizontally installed multi-circuit outdoor coil. In addition, the negative effects of melted frost retained on the airside surface of the experimental horizontal three-circuit outdoor coil due to surface tension on defrosting performance were demonstrated. Two measures of manually cleaning the melted frost and reversing the rotation of the outdoor air fan to blow away the melted frost were examined.

Acknowledgements

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Biography

Mr Song Mengjie is a Ph.D. candidate of the Department of Building Services Engineering in the Hong Kong Polytechnic University. His research interest is defrosting study for an ASHP unit having a multi-circuit outdoor coil.